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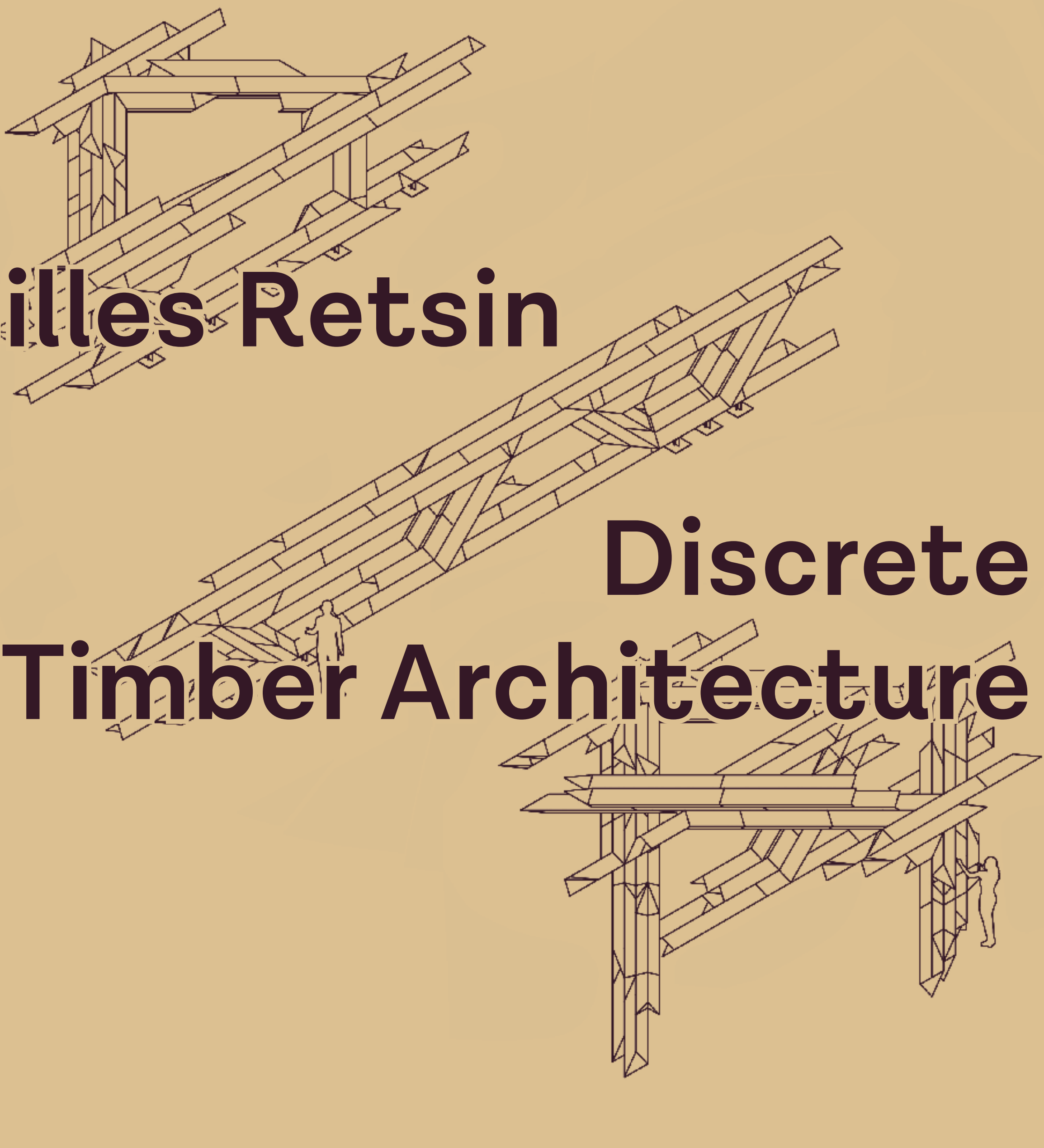

Gilles Retsin

Discrete Timber Architecture

BARTLETT DESIGN RESEARCH FOLIOS

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Discrete Timber Architecture


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1 (previous) Modularity is understood in a digital way, giving rise to a seemingly monolithic architecture that can always be brought back to its elementary parts.

2 Tallinn Architecture Biennale installation, 2017.

Project Details

Author	Gilles Retsin
Title	Discrete Timber Architecture
Output Type	Design and construction
Function	Prototypes for building construction
Exhibitions	Bi-City Biennale of Urbanism/Architecture, Shenzhen (2019) Royal Academy of Arts, London (2019) SCI-Arc, Los Angeles (2018) Tallinn Architecture Biennale (2017)
Dates	2017 to 2019
Commissioning Bodies	Bi-City Biennale of Urbanism/Architecture, Shenzhen; Royal Academy of Arts, London (RA); SCI-Arc, Los Angeles; Tallinn Architecture Biennale (TAB)
Selection Committees	Fabio Cavalucci, Meng Jiangmin, Manuel Lietti, Carlo Ratti (Bi-City); Kate Goodwin, Gonzalo Herrero (RA); Michael Hensel, Triin Ojari, Claudia Pasquero, Martin Tamke (TAB)
Curators	Fabio Cavalucci, Meng Jiangmin, Carlo Ratti (Bi-City); Kate Goodwin, Gonzalo Herrero (RA); Herwig Baumgartner, Marcelyn Gow (SCI-Arc); Claudia Pasquero (TAB)
Design Teams	Doguscan Aladag, Yiyun Kang, Andrei Martin, Kevin Saey (Bi-City); Kevin Saey, Johan Wijesinghe (RA); Man Nguyen (SCI-Arc); Ivo Tedbury, Oscar Walheim (TAB)
Research Assistants	Kevin Saey, Ivo Tedbury, Oscar Walheim, Johan Wijesinghe
Co-Exhibitors	Stefano Boeri, Thomas Heatherwick, Ryoji Ikeda, OMA, Francois Roche, SideWalk Labs, Roland Snooks, Liam Young, Philip Yuan/Archi-Union (Bi-City); ScanLab (RA); Coop Himmelb(l)au, Izaskun Chinchilla Architects, Enric Ruiz-Geli, Vogt Landscape Architects (SCI-Arc); BiotA Lab, ecoLogicStudio, IAAC Barcelona (TAB)

Consultants	PLP (Bi-City); YIP Engineering (TAB, RA)
Fabricators	Cut-Tec, steel cutting; Shanghai Bo-Hai (Bi-City); Wup Doodle, CNC fabrication (RA); CNC Studio (TAB)
Funding Awards	£5,000 British Council; £15,000 TAB; £20,000 RA, including material sponsorship; £20,000 Bi-City Biennale, partly sponsored by PLP; $5,000 SCI-Arc


3

3 Real Virtuality at the Royal Academy of Arts, London, 2019.

Statement about the Research Content and Process

Description

This research develops a new design paradigm for timber architecture, based on discrete building blocks that can be cut from widely available sheet material.
On a technical level, the research develops a computational design and fabrication method where assembly becomes a truly digital process; on a socioeconomic level, it argues for the development of an open, distributed platform for timber construction, which can increase access to housing; and on an architectural level, it introduces higher degrees of complexity and versatility in modular construction.

Questions

1. How can we design versatile, scalable, Lego-like building blocks from timber sheet materials?

2. How can we develop more accessible and democratic means of automated construction with timber, enabling an open-ended, circular and distributed platform for construction?

3. What are the consequences and implications of this discrete approach in the construction of buildings?

Methodology

1. Discrete computational design and fabrication methods;

2. Large-scale prototyping and iterative testing, in collaboration with structural engineers;

3. Experimental proposals for full-scale buildings;

4. Theoretical and historical framing through writing and the peer-to-peer community.

Dissemination

The work has been discussed in eight published articles by the author, including the *AA Files* (2019). It has featured in 13 peer-reviewed papers and 20 online articles.
The work has also been discussed in seven academic papers for conferences, including ACADIA 2019 in Austin, and has led to two keynotes and 32 public lectures, including a symposium organised by the Swiss Architects' Association in Zurich on digital fabrication. It has also been exhibited internationally and has been shown at five biennales.

Project Highlights

The work led to a first prize at the Tallinn Architecture Biennale, a direct commission for an installation at the Royal Academy of Arts in London, and a solo show at MBUS Design Gallery in Miami. Further to this, it has resulted in an invitation to co-edit two books related to the topic: *Discrete: Reappraising the Digital in Architecture* for *Architectural Design* (2019) and *Robotic Building: Architecture in the Age of Automation* for *Detail* (2019). On the basis of this work, Retsin has held visiting professorships at RMIT University and The University of Hong Kong.

4 Tallinn Architecture Biennale installation, 2017.

4

Introduction

The concepts of the continuous and the discrete exist in mathematics, information science and philosophy. Analogue data is continuous, meaning that a signal can take any value in a range; while digital data is discrete and consists of finite parts. Traditionally, architects use analogue, continuous elements to design a building. They usually establish overall ideas or forms from the outset and then derive the elements required to realise them. The parts of these buildings are in a continuous range related to the whole. A concrete shell would be the most obvious example of a continuous architecture, as there are no parts and it can be described mathematically by a differential formula; however, a shell made of bricks is also continuous, as the position of the bricks derives from the shell as a whole. In the case of the latter, the brick is discrete before it is bound by mortar, which allows it to continuously change its position in relation to the vault as a whole.

A typical modernist project using prefabricated elements such as Aldo van Eyck's Amsterdam Orphanage (1960) **(7)** is in some respects a discrete form of architecture, as it makes use of a reduced set of parts which have limited ways to connect to each other; the overall form relies on the parts. It is not 'digital' as parts are still understood as strict, hierarchical architectural types – columns, beams and cupolas – that require an overarching geometric grid to be arranged and can only appear where they perform their specific function. To qualify as digital, the architectural part would have to be a generic and versatile building block, which gives rise to functions and features only after combination with other building blocks. The resulting whole in this case is always dependent on time; as elements are added or removed the whole transforms. This computational understanding of the architectural part is what the discrete paradigm explores.

The origins, or the technical logic, of the work relates to Hod Lipson's programmable matter research **(6)**, MIT's CIAL modular robotics and the Digital Material Research at the Centre for Bits and Atoms, with projects such as Flexural Materials by Kenneth Cheung and Bill-E by Benjamin Jennett **(8)**. The Harvard Wyss Institute's TERMES robots project is another reference **(5)**, where a distributed robot assembles serialised building blocks. Digital materials can be precisely defined as a discrete set of parts, which are reversibly joined with a discrete set of relative positions and orientations (Cheung 2012). Gerschenfeld proposes that 'digital fabrication' is a process that compiles these parts, whereas analogue fabrication is based on a continuous subtraction or deposition of matter (Gerschenfeld et al. 2015), for example 3D printing and robotic milling. The work presented here attempts to define structural building parts that share some of the properties of the generally smaller-scale digital materials or programmable matter building blocks. The principles of programmable and digital materials are combined with existing knowledge of prefabrication, modular construction and design for manufacturing and assembly (DfMa) **(9)**. Digital materials and programmable matter aim to automatically or autonomously manufacture functional machines or infrastructures from smaller base units. Architecture, in its most basic sense, attempts the same: assembling functional buildings from smaller parts.

Discrete architecture redefines the digital as most work perceived as such is actually analogue and continuous, due to its use of computers, when looked at through the

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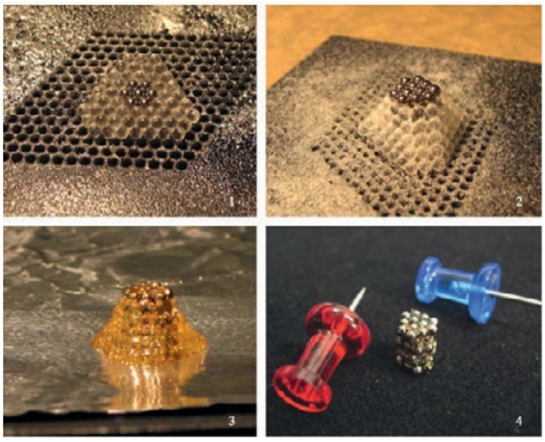

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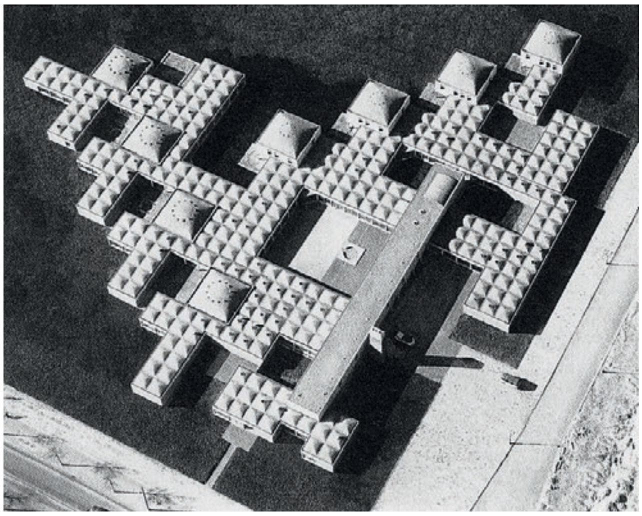

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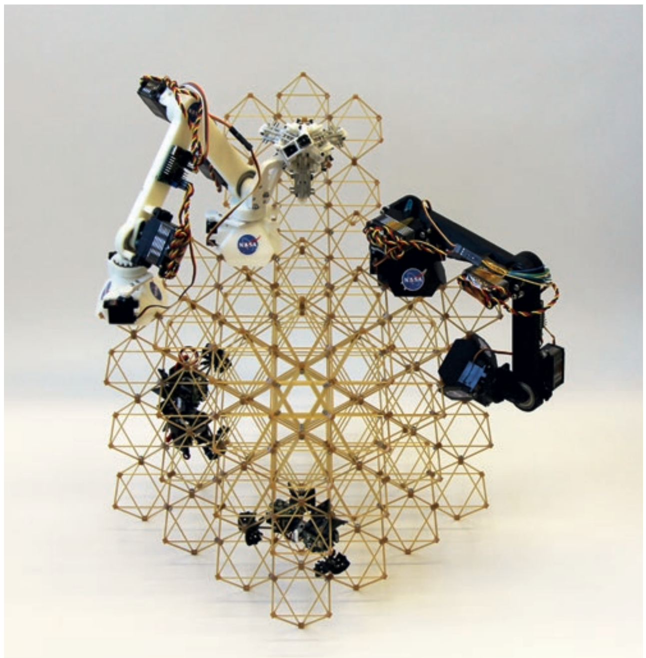

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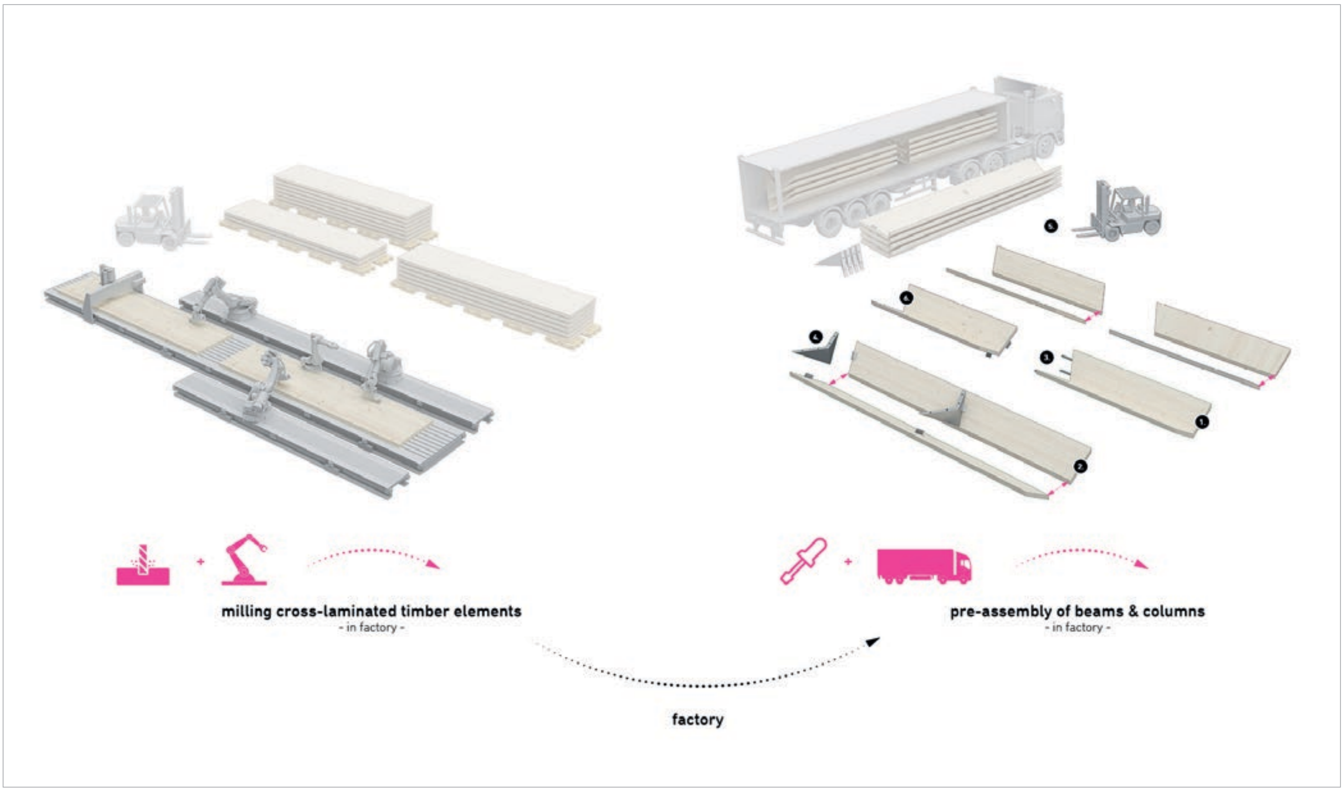
5 Wyss Institute's TERMES robots.

6 Hod Lipson, research on programmable matter.

7 Aldo van Eyck, Amsterdam Orphanage, 1960.

8 BILL-E 2 robot, MIT Center for Bits and Atoms.



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9 Discrete timber capitalises on automated prefabrication. Industrial robots cut standard sheets of timber into parts that can be assembled into building blocks before being transported to site.

10

10 The Tallinn Architecture Biennale installation is one of the first full-scale prototypes of a discrete timber architecture. It was designed as an abstract fragment of a larger house, rather than as a pavilion.

framework described here. A truly digital understanding of the discrete part has radical consequences for architecture. It enables a higher degree of automation, but also combines the efficiency and scalability of modular prefabrication with complexity, open-endedness and adaptability. Construction evolves from a capital-intensive, centralised process into a digital form that is accessible and easily distributed.

The research presented here is one of the first to combine timber fabrication with discrete computational design. The Tallinn Architecture Biennale pavilion was the first large prototype of the digital discrete **(10)**. The work has developed knowledge on a technical level through 1:1 prototyping, but also on an architectural and theoretical level. It has formed economic and social insights into automated timber platforms, and investigates the technical development of discrete timber blocks, the implications of automation on the construction industry and its social potential for creating housing. The work has also contributed to bringing housing into the digital design discourse.

Timber was chosen because of its positive environmental qualities, its structural properties, scalability and high-degree of automation. It is also easy to customise with computer-controlled machines. Three projects – the Tallinn Architecture Biennale installation (2017) **(18–20)**, Real Virtuality at the Royal Academy (2019) **(38–40)** and a proposal for the Nuremberg Concert Hall (2018) **(11)** – explore a design framework where architectural, socioeconomic and technical questions are synthesised to argue for the broader use of automated discrete timber production in housing and the building industry at large.

11 The proposal for the Nuremberg Concert Hall, 2018, demonstrates the application of discrete timber structures for complex, large-scale buildings. It consists of repeated sections of CLT modules, robotically prefabricated offsite.

11

12

12 Housing is an important programme for the discrete agenda. This proposal for a housing block explores the application of a system such as that developed for the Tallinn Biennale.

Aims and Objectives

The work aims to explore a discrete and digital approach to timber construction, arguing that it is the best material for a complex, scalable and open-ended architecture with a high degree of automation. This has technical, socioeconomic and architectural consequences.

On a technical level, the work aims to develop an architecture that only consists of a limited set of repeating, serialised but versatile building blocks, digitally processed from simple timber sheet materials **(13)**. It uses 1:1 prototypes to test these timber building blocks and develops propositions for larger residential and cultural buildings. The short, modularised, automated production chain aids the distribution of these blocks, enabling access and a decentralised network of production. As only one modular element needs to be produced, fewer steps and machines are required to automate the construction process. The traditional building industry uses hundreds of different parts and processes to construct a building, which makes it difficult and expensive to automate. By reducing the part count, the procurement process radically changes because discrete building elements can be made with a few digital machines in small factories or workshops **(14)**.

On an architectural level, the work aims to understand the consequences of an architecture without whole, meaning that the building consists of parts that are not derived from an overall design. The parts exist independent of an actual building and should be able to construct and reconstruct a complex variety of outcomes. The form and structure of the building is dependent on the parts, and never final. The discrete parts have no specific function and there are no designated tectonic elements such as columns, beams or floorplates. By iterating in scale between 1:1 prototypes and fully fledged buildings, a discrete architectural syntax that rejects fixed hierarchies and typologies is advanced.

Questions

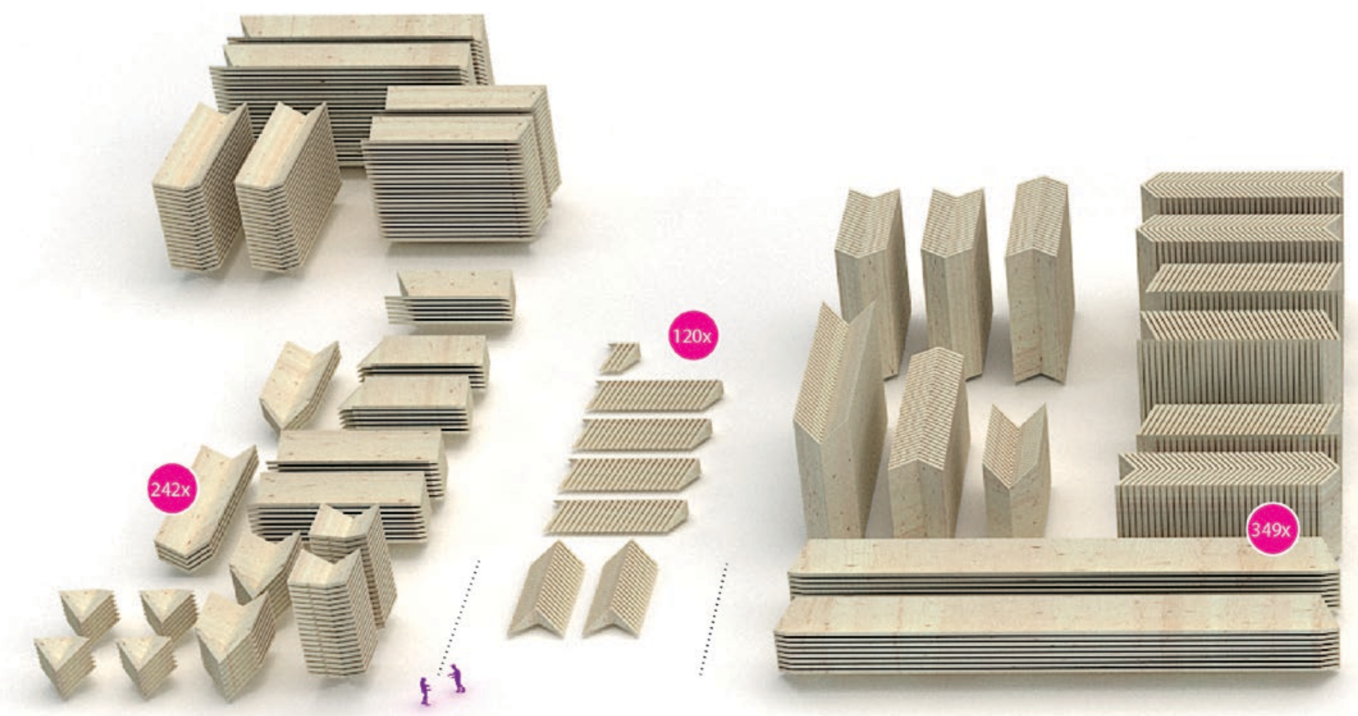
1. How can we design versatile, scalable, Lego-like building blocks from timber sheet materials?

Timber construction is historically considered a discrete method, where separate elements are assembled into larger wholes. Timber buildings can also be broken down again to their base elements, however, these parts are typically functional types such as columns or beams that can be reassembled in predictable typologies and forms. Discrete timber proposes versatile function-less elements with no specific tectonic purpose.

On a technical level, this research attempts to transfer some of the core-concepts of 'digital materials' to architectural modularity, establishing a short, integrated and continuous production chain based on generic, serialised and versatile building blocks. These blocks are digitally fabricated from sheet materials, with limited connection possibilities and passive error correction. They are function agnostic and exist independently of an actual building. They are, therefore, able to construct a complex variety of outcomes. This idea is often compared to molecular biology, in which all lifeforms are assembled from just 20 standardised amino acids conceived as modular building blocks (Langford 2019). Moreover, this approach leads to a short and continuous production chain, where assembly becomes a digital process of combining repeating base elements, not dissimilar to additive manufacturing (Hiller and Lipson 2009).

2. How can we develop more accessible and democratic means of automated construction with timber, enabling an open-ended, circular and distributed platform for construction?

The small-scale infrastructure needed to construct building blocks and assemble buildings would make construction more accessible, faster and less capital-intensive, opening the market to a larger group of house builders. Housing can be assembled, disassembled and adapted much quicker, which in turn questions modes of ownership, forms of domesticity and procurement. The possibility of disassembling, moreover, has important ecological implications, as these building blocks can be continuously recycled in other buildings. Moreover, by liberating housing from fixed types and typologies, this discrete approach to timber allows for a multiplicity of residential spaces and modes of living **(12, 22)**.



CLT - Elements Folded

Type t-h7: 28x
Type t-h8: 16x
Type t-h9: 36x
Type t-h6: 20x
Type t-h5: 16x
Type t-h4: 6x
Type t-h3: 42x
Type t-h2: 78x

Total: 242 pieces

CLT - Elements Folded

Type t-v8: 120x

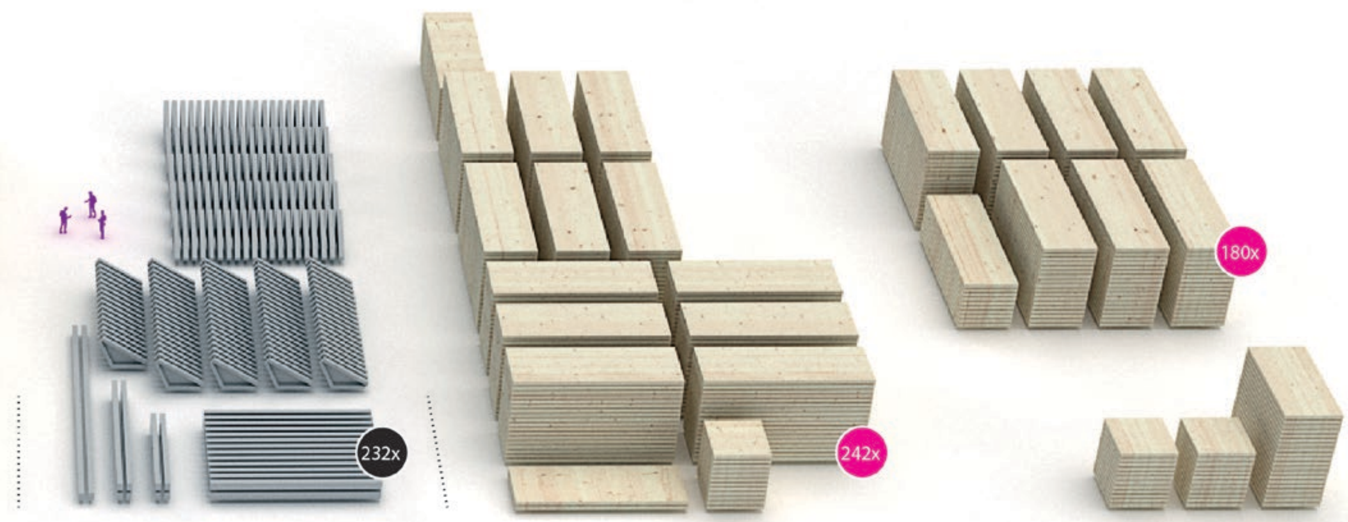
Total: 120 pieces

CLT - Elements Folded

Type t-h1: 16x
Type t-v1: 34x
Type t-v2: 32x
Type t-v3: 17x

Type t-v4: 128x
Type t-v5: 60x
Type t-v6: 30x
Type t-v7: 32x

Total: 349 pieces



GRC - Facade Elements

Type g-1: 30x
Type g-2: 4x
Type g-3: 2x
Type g-4: 196x

Total: 232 pieces

CLT - Floor Plates

Type t-p4: 110x
Type t-p1: 12x
Type t-p3: 120x

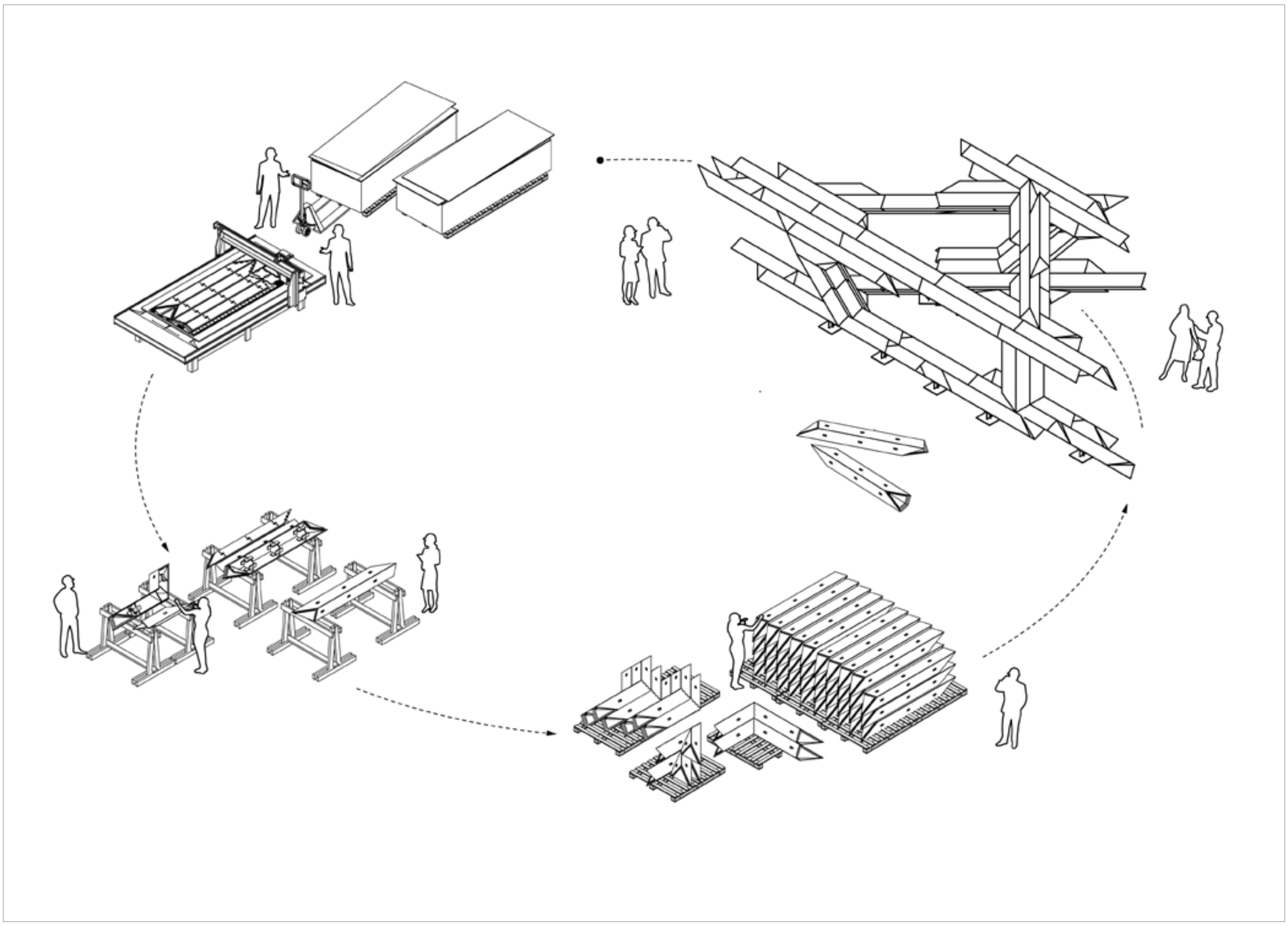
Total:242 pieces

CLT - Floor Plates

Type t-p1: 24x
Type t-p3: 156x

Total: 180 pieces

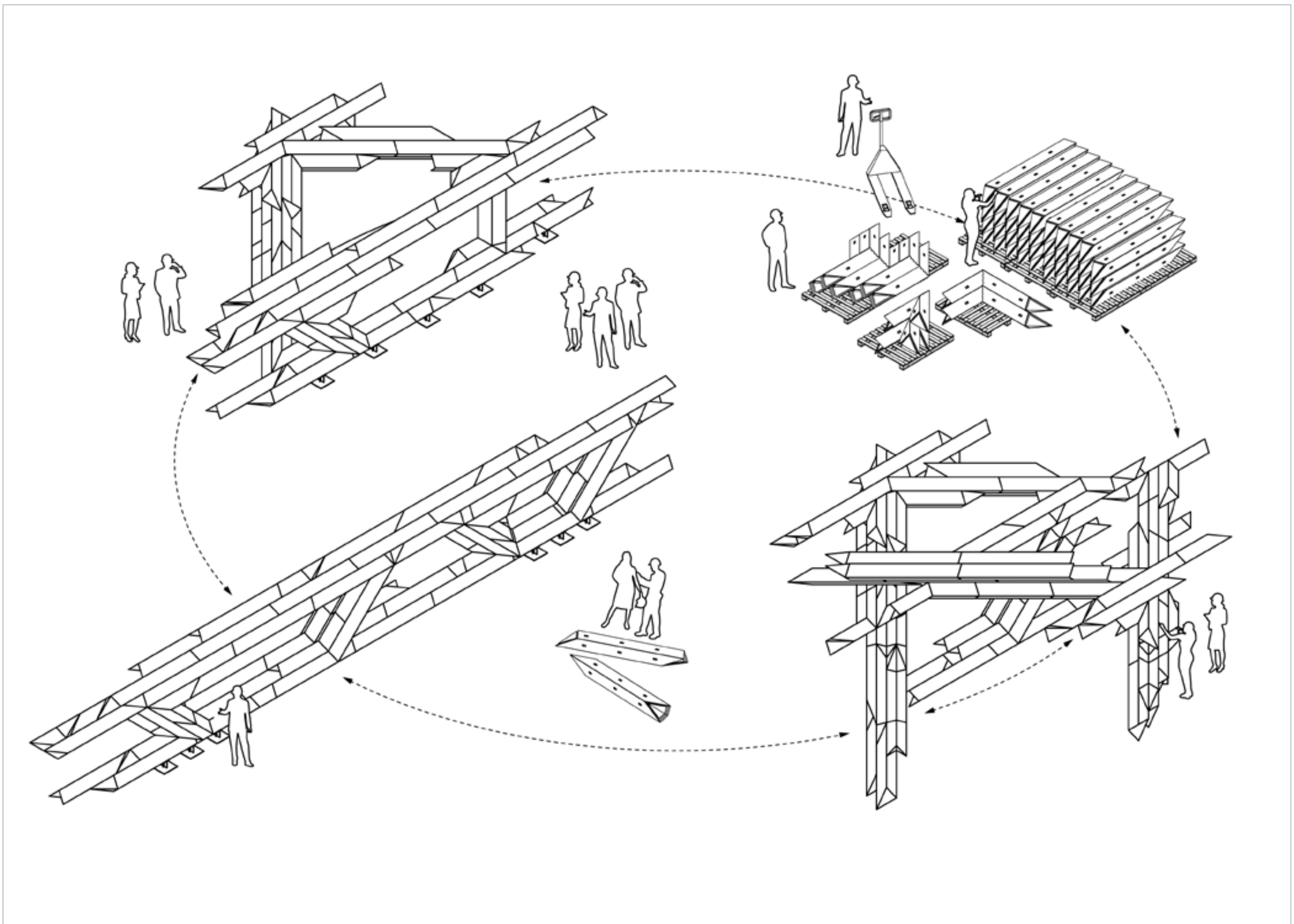
13



14

13 (previous) The complex programme of the Nuremberg Concert Hall completely flat-packed and prefabricated from timber sheets. The high repetition of elements allows for efficient production, repeatability and fast assembly onsite.

14 Discrete timber allows for a short and integrated production chain, where only a few machines and tools are needed from beginning to end. In the case of the Tallinn Biennale installation, a simple CNC machine and standard sheets of timber were used.



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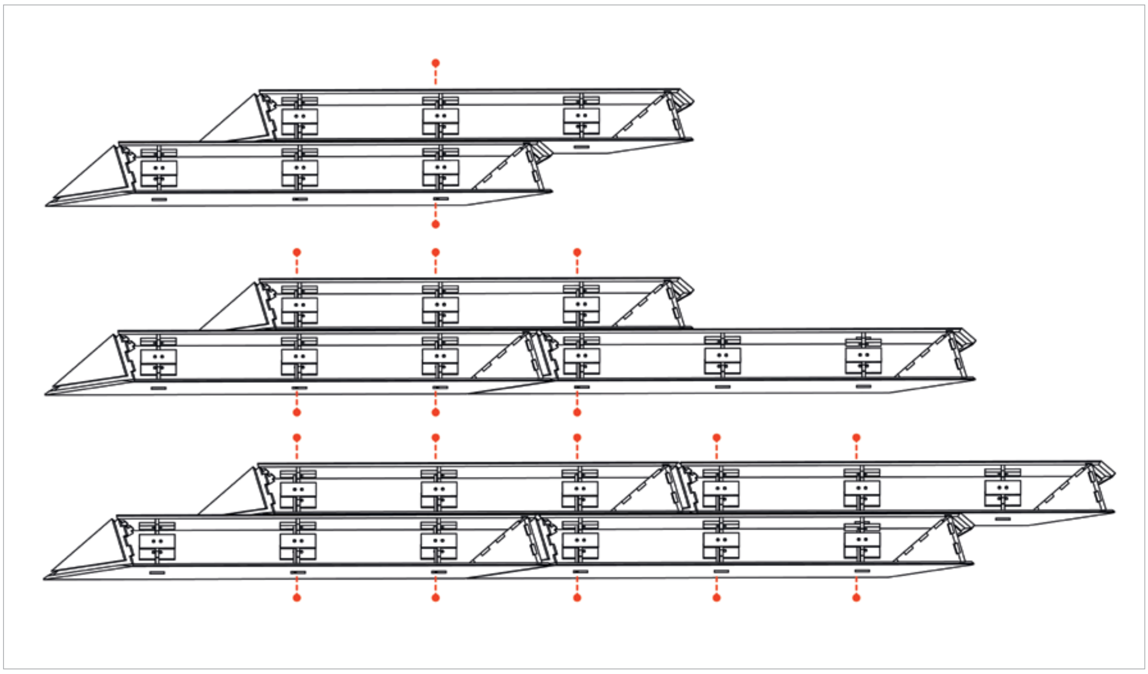
15 The building blocks are versatile elements that can be used for multiple different designs. This implies a circular form of construction, whereby a building can be deconstructed and reassembled in a new form.



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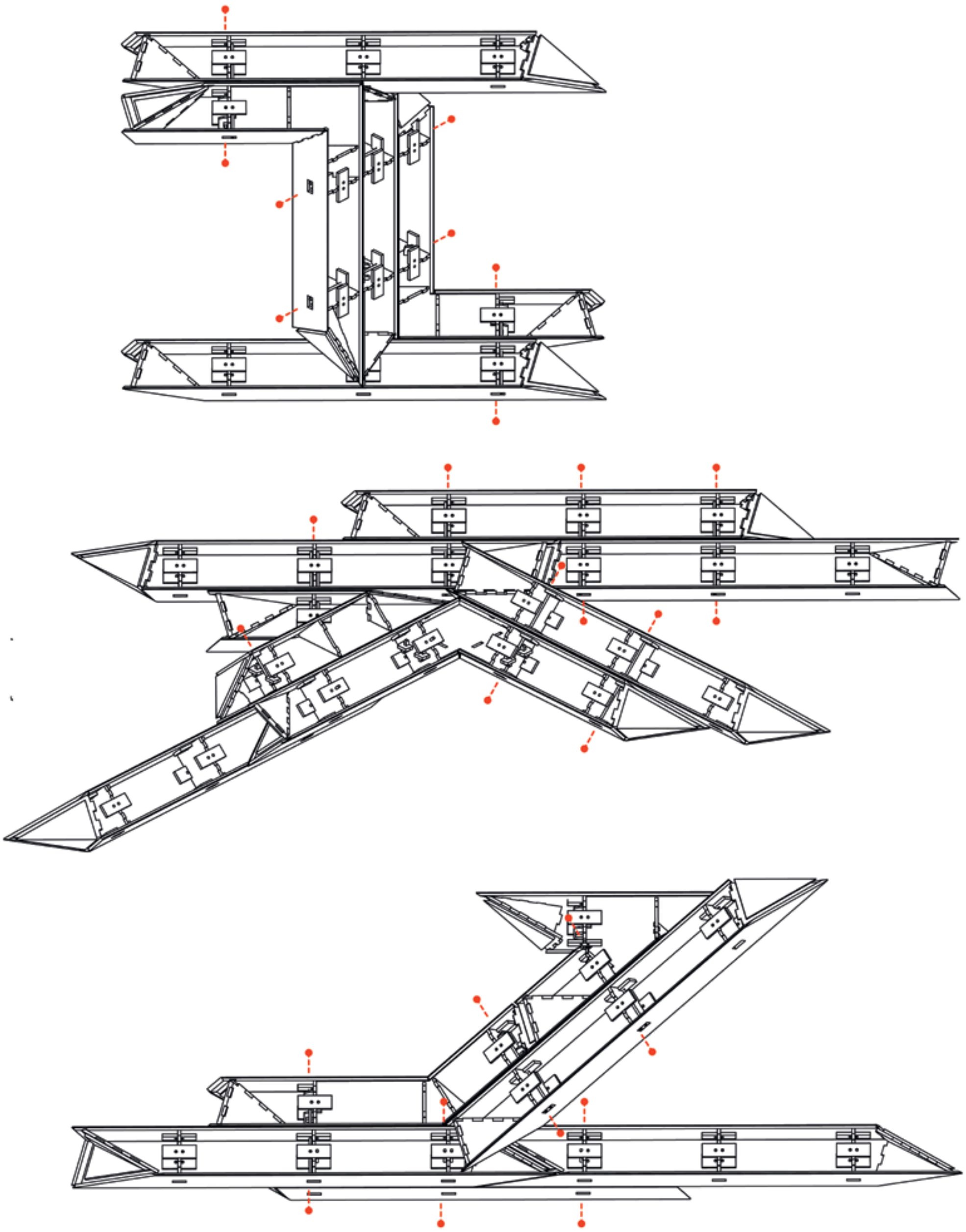
16–7 Plywood building blocks are connected under tension, using threaded rods. This creates structurally continuous, monolithic elements.



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18–20 Tallinn Architecture Biennale 2017.

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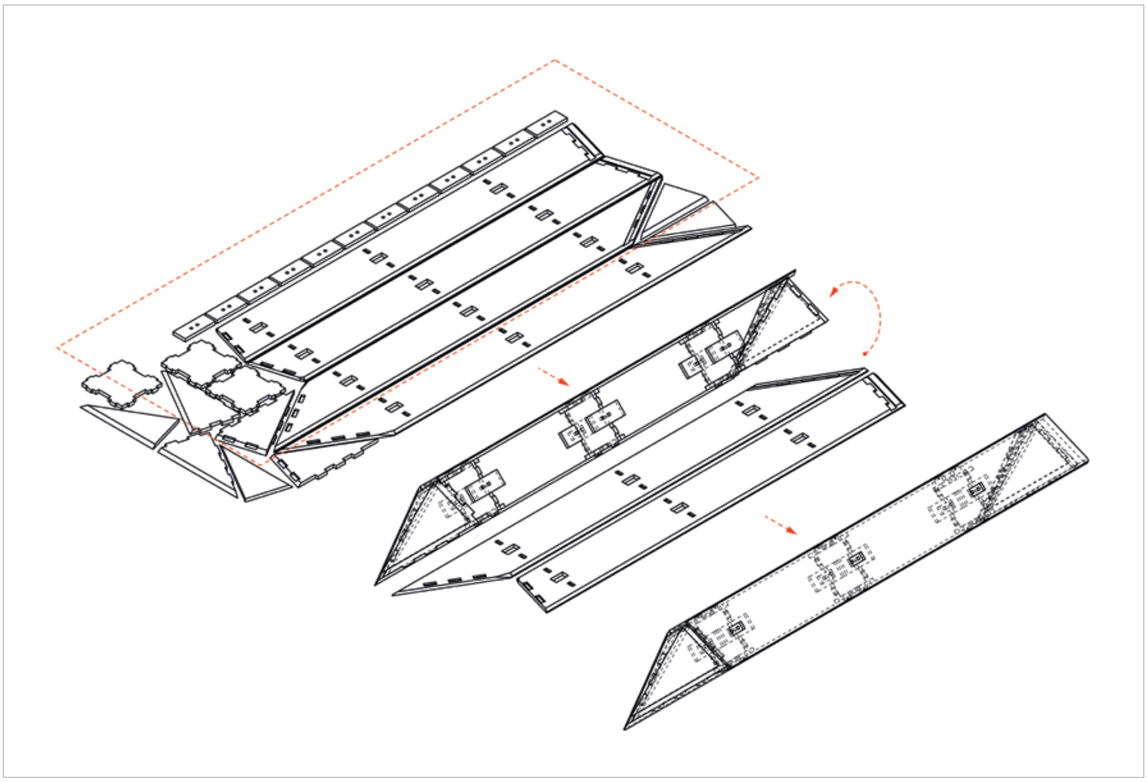
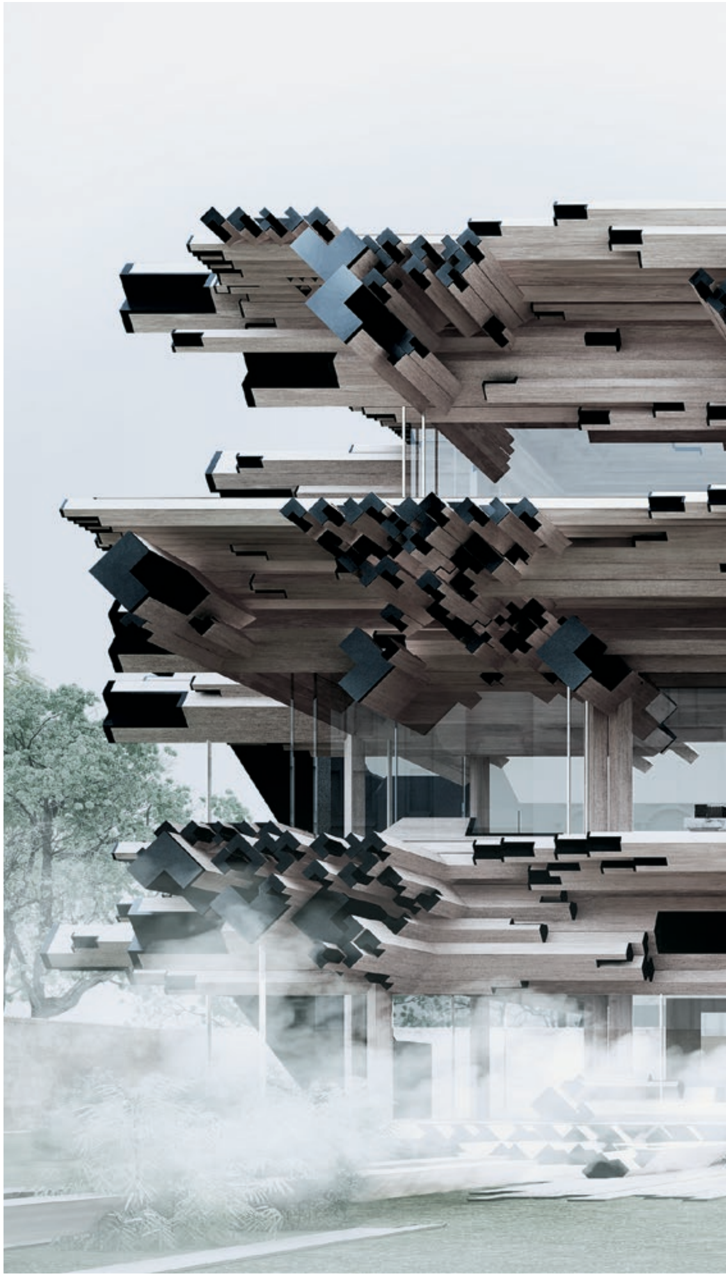


21

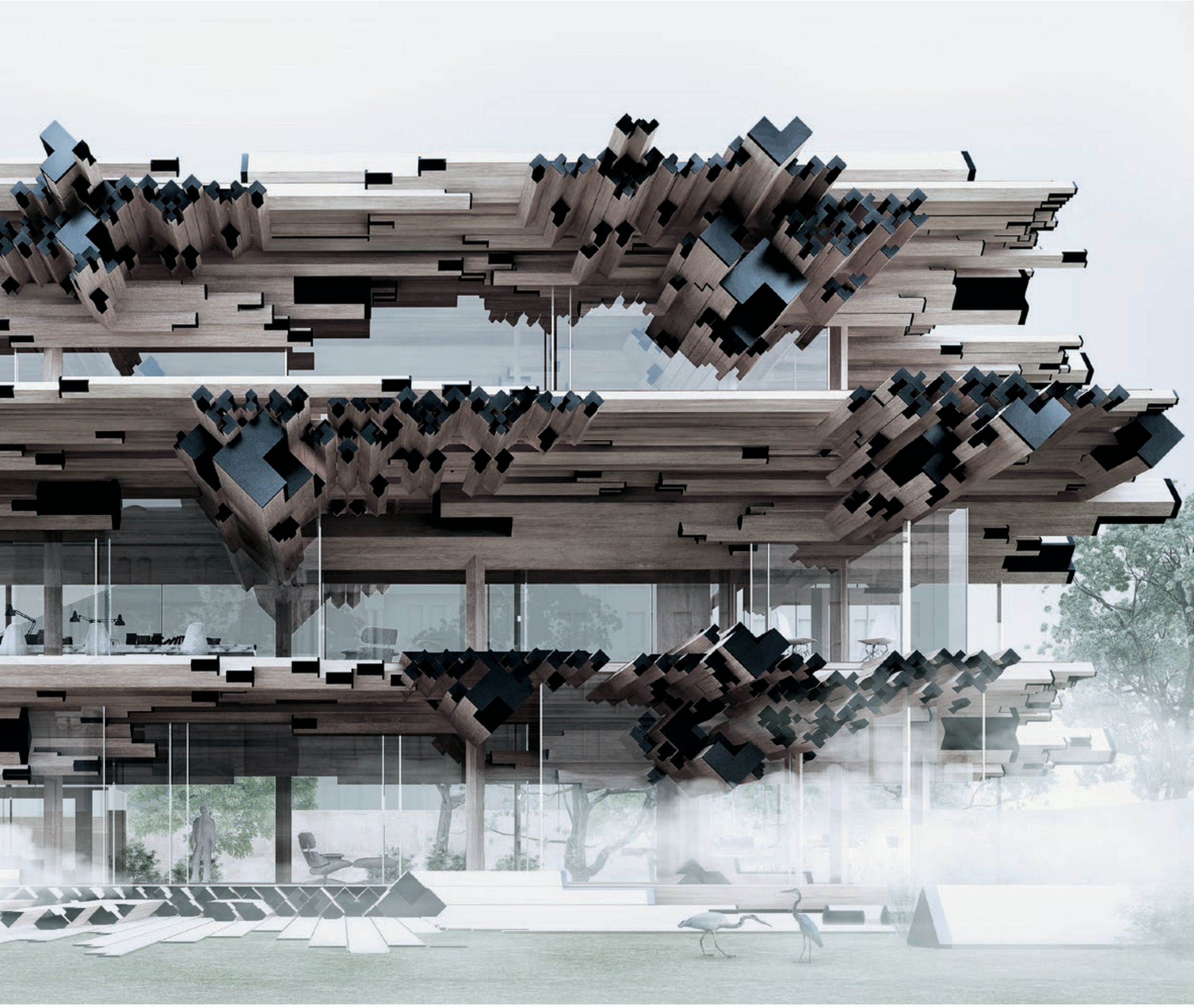
21 One standard sheet of timber is cut into parts that can then be assembled into a building block. This building block is engineered to perform in any structural condition and is never optimised for a specific function.

3. What are the consequences and implications of this discrete approach in the construction of buildings?

On an architectural level, the digital discrete part does not have a predefined role, nor is it subjected to overall form or singular function; instead, it remains independent of the architectural whole. It is only after the part is combined with other elements that it establishes functional features and properties. There is no longer an overarching super-form that defines the position of the parts. The parts maintain their autonomy and effectively diffuse the architectural whole. Breaking the modernist form-function logic, which tends to result in a hierarchical assembly of fixed architectural types, this discrete architecture is now almost organic: one element and its properties define everything. As the discrete part is universal and versatile, it appears in every instance. Whereas a column can only act as a column, a discrete part can be used universally throughout the building. A number of discrete parts can be assembled to perform as a column, but the same parts could also be assembled to perform as a floor slab **(23)**.



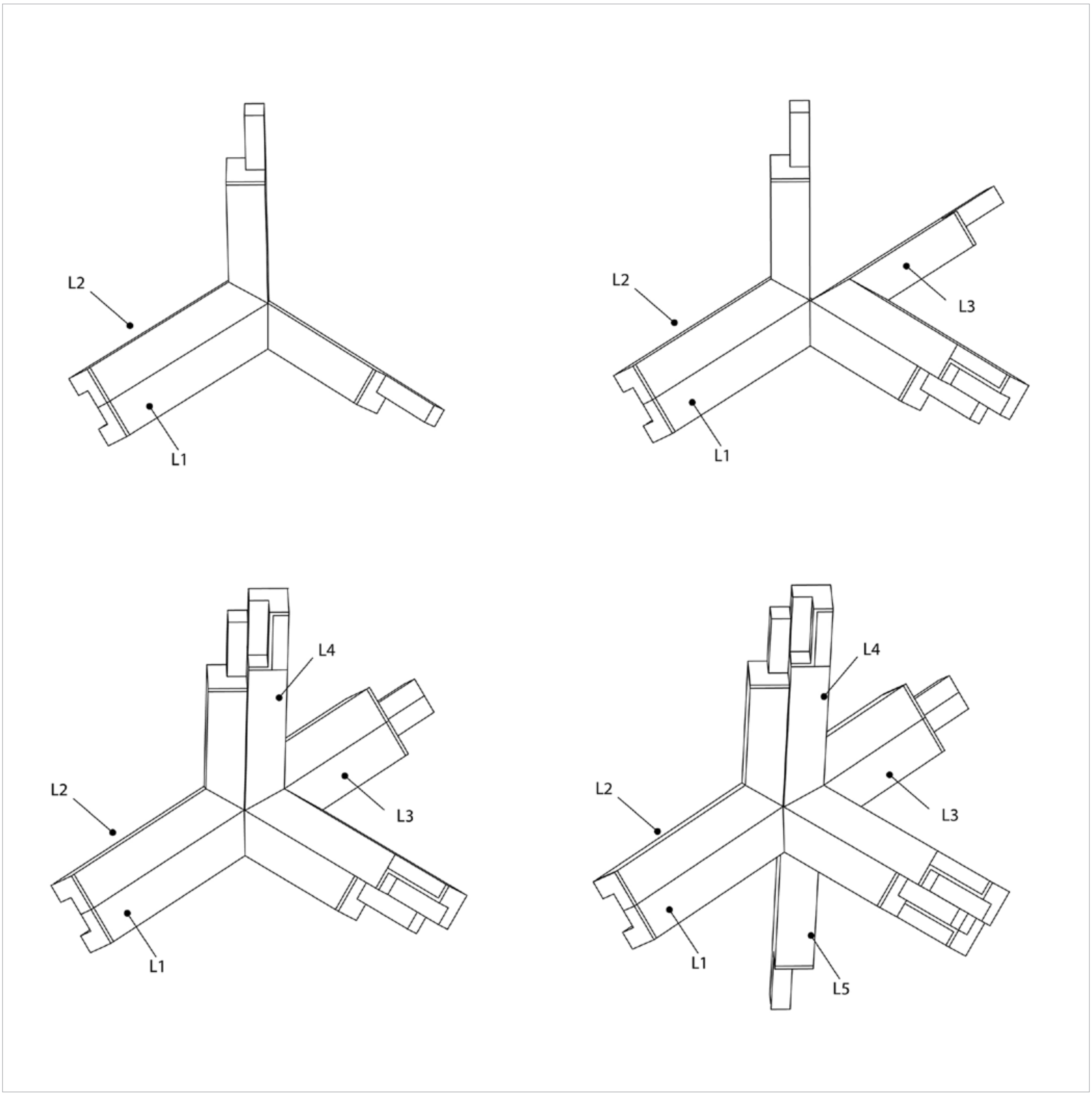
22 The Diamonds House is a proposition for a multi-family house in Belgium, built from repeating modules similar to the ones used at the Royal Academy. While looking visually excessive, it is a mere repetition of the same modular element.



23

23 Interior of The Diamonds House. Architecture is, in this case, only defined by part-to-part relations. The building is made from repeating parts, without any typology or overarching geometry, resulting in an organic, cave-like space.

24 The building blocks in themselves are function agnostic, meaning that function only emerges after the combination of the elements.



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Context

Timber Construction

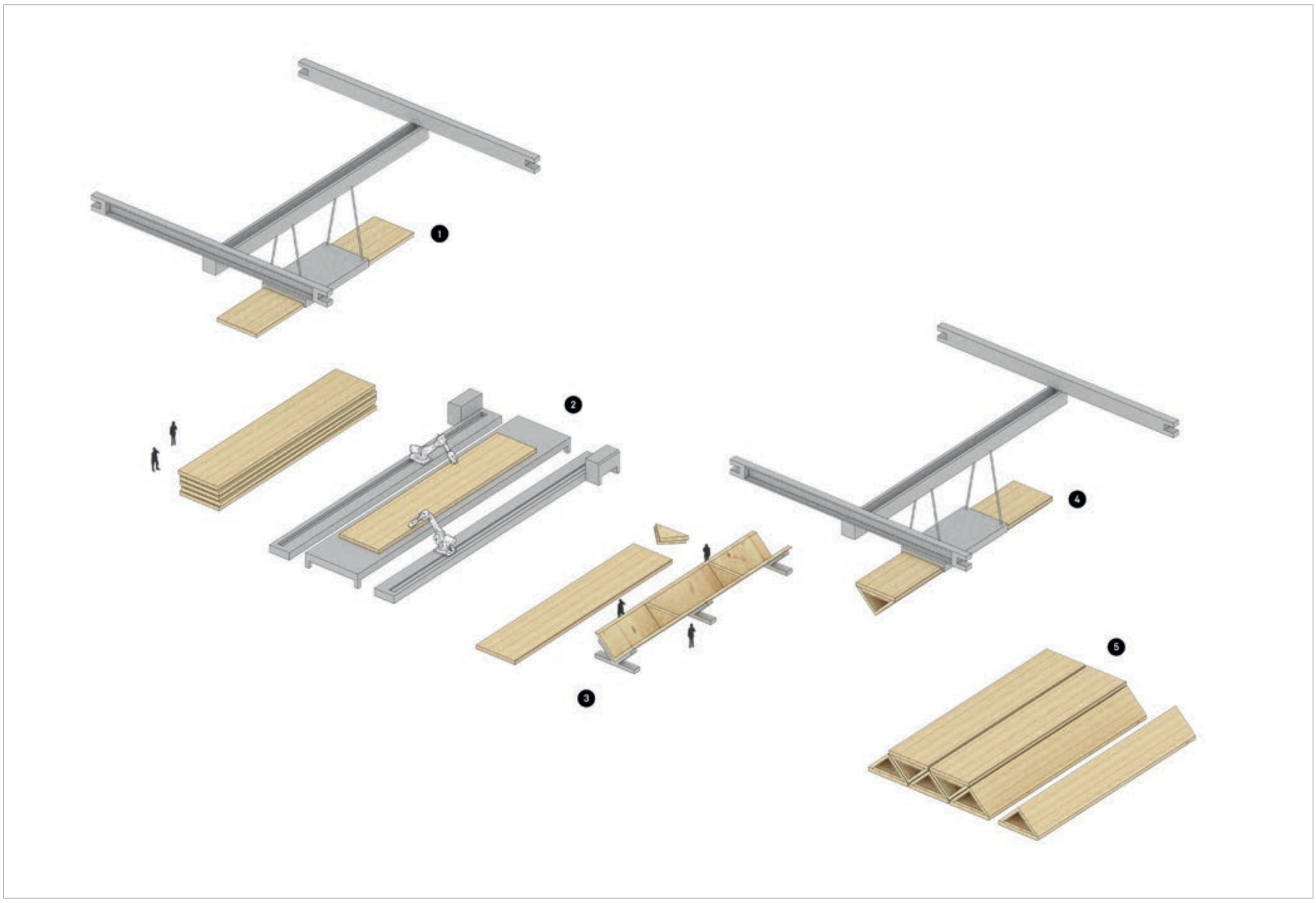
The last decade has seen a rapid development of engineered timber materials such as Cross Laminated Timber (CLT) and Laminated Veneer Lumber (LVL). While timber has been historically associated with craft and bespoke construction, Computer Numerical Controlled (CNC) cutting machines and robotics bring to this material new possibilities. Timber materials such as CLT create new freedoms and possibilities for designers. Timber sheets are now available in unlimited weights and sizes and can easily be cut into any shape using a digital cutting machine, while their strength can be controlled in detail. Traditionally, timber elements were defined by the size and direction of fibres in a tree. By overlapping strands of timber, the timber element obtains the same strength in all directions **(25)**.

Global interest in the use of timber has been generated by architectural ideas for 'timber skyscrapers', and also the environmental crisis as it is a carbon neutral material. Under pressure from a worldwide housing crisis and a general lack of automation in the building industry, the idea of modularity and prefabrication has also made a comeback. Prefabrication and modularity allow for a more integrated construction process, usually reducing material waste and the room for error. While prefabrication is often associated with uniform and repetitive building forms, when used in combination with digital production it can increase the degree of architectural freedom and customisation.

The combination of digital cutting and engineered timber questions the fixed nature of architectural types. Traditionally, timber construction was reliant on the fixed dimensions of lumber, which resulted in defined methods and assemblies such as in timber framing. By shifting to flat sheets of engineered timber, this logic is put into question and subsequently asks for new architectural design strategies **(26)**.

25 While timber was traditionally restricted to limited sizes of lumber, new engineered timber, such as CLT, allows for limitless lengths. These can be automatically assembled into modular building elements with precise properties.

26 A limited library of parts for Nuremberg Concert Hall. The entire building is constructed from repeating V-shaped building blocks, which appear as walls, columns and floors.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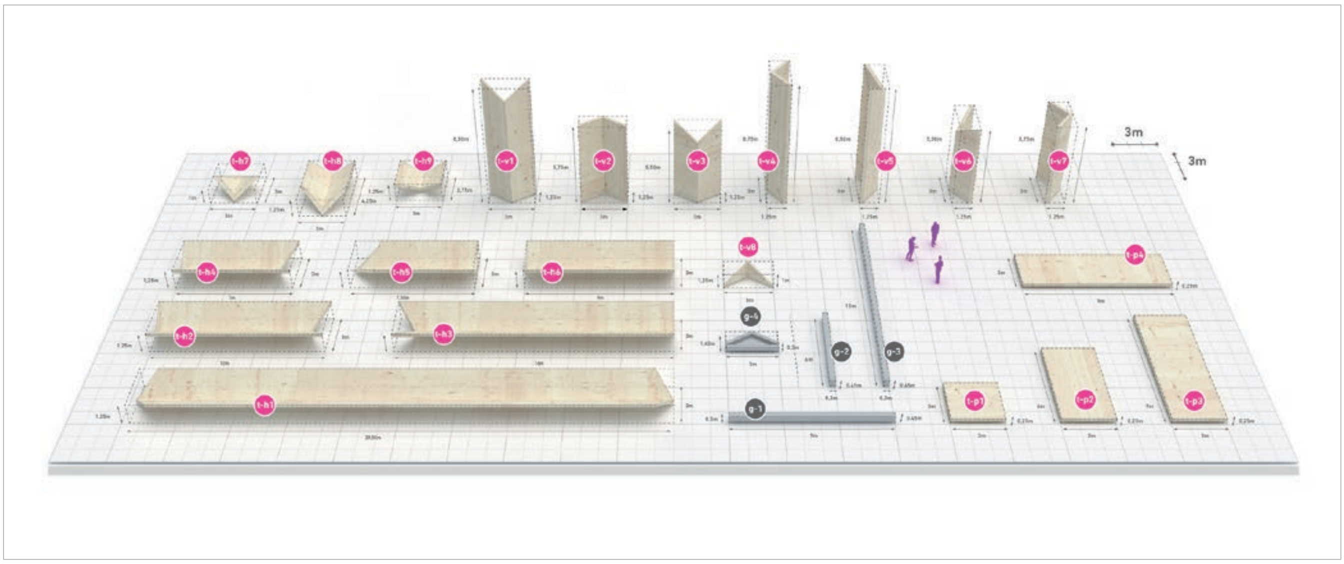
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t-v7
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3m
t-h4
t-h5
t-h6
t-v8
t-p4
t-h2
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g-4
g-2
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t-p3

26

Platforms and Automation

In the context of increasing labour and decreasing robotic costs, a so called 'automation gap' (Claypool 2019) leads to an ever-decreasing productivity in construction. The construction industry has flatlined since 1947, whereas manufacturing has radically increased its productivity through higher degrees of automation (McKinsey 2017). As building is slow and expensive, only a limited number of actors can take the risk to construct. This keeps the market limited and scarce in supply of housing, and puts the decision making of construction in the hands of the few; namely, government and large developers. Cooperative efforts to construct housing have proven difficult to scale, again partially as a result of complicated construction and procurement.

In response to the housing crisis and flatlined productivity, there is a renewed interest in modularity and prefabrication. Design for Manufacturing and Assembly (DfMA) and modular timber construction aim to take as much labour offsite as possible. These approaches can't radically improve productivity, however, as the production chain is still discontinuous, analogue and difficult to automate. Moreover, DfMA is increasingly linked with centralised, capital-intensive platform companies.

Today, Alphabet's Sidewalk Labs is digitally planning entire neighbourhoods, while companies such as Katerra attempt to overhaul traditional construction and architecture with venture capital-backed modular timber construction, purchasing multiple architecture offices along the way, such as the celebrated Vancouver-based Michael Green Architects (Katerra 2019). Novel hybrids of real-estate development and lifestyle brands, such as The Collective, are developing shared-living communities around the world and are shaping new forms of domesticity. They offer a catalogue of fixed modular timber parts, such as columns, beams, floor cassettes and façades that can be applied to various buildings.

Theories post 2008

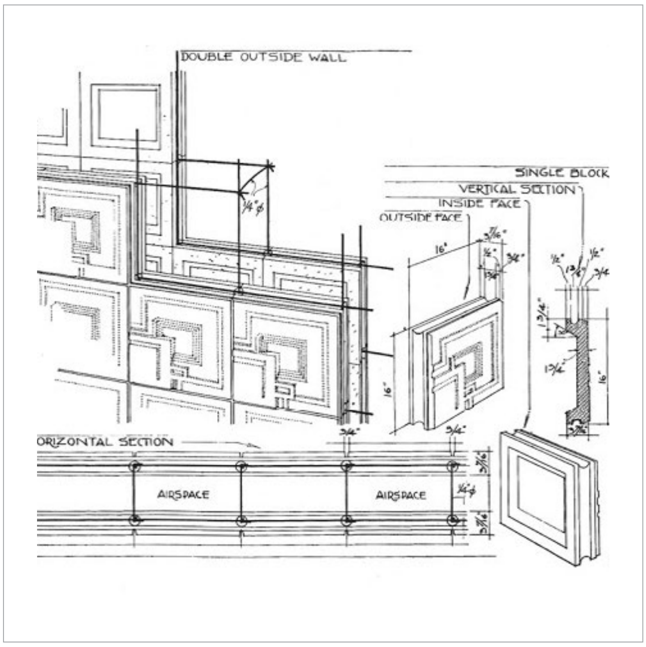
Dominating the architectural discourse following the 2008 financial crisis, the digital in architecture – or what Mario Carpo refers to as 'the first digital turn' (Carpo 2014) – became associated with troublesome neoliberal politics and a corresponding lack of social awareness. Carpo's 2014 article 'Breaking the Curve' revealed some of the inner contradictions of the paradigm of continuity that had emerged over the past two decades of digital research. He posits that the continuous, spline-based work has little in common with today's computation itself, which is essentially a discrete process (Carpo 2014). A new generation of architects started to criticise the accepted notion of digital production as a form of mass-customisation of curved form, such as EZCT with the Generative Chair (2004) **(27)** and Universal House (Morel 2011). Other architects, such as Jose Sanchez, began to advocate an agenda that is socially conscious, attempting to democratise the process of design while also criticising the starchitect-driven model with its doubtful labour practices (Sanchez 2018). Mollie Claypool continued this criticism with a connection to automation and feminism (Claypool 2019). This emerging body of work, referred to as 'discrete' in contemporary architectural discourse, advances an architectural paradigm that emphasises the combination of automation and parts (Claypool 2019).


27

27 EZCT, Generative Chair,
2004.

Unlike the modernist kit-of-parts approach favoured by new timber platforms, the discrete approach starts from an inherently digital understanding of parts as generic building blocks, which through their combination and interaction can establish functionality. This approach emphasises the discrete nature of computation (Carpo 2014) and reframes architectural parts as voxel-like units (Morel 2011), which can be variably organised and programmed.

Alongside the above, the discrete discourse has reconnected with historical precedents for computational design. For example, the work of Albert Farwell Bemis **(29)** and Leonardo Mosso and their precedents of a voxel-based architecture (Botazzi 2018), as well as Frank Lloyd Wright's Textile Block Houses, (c.1924) **(28)**.



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28 Frank Lloyd Wright, Textile Block Houses, c. 1924.

29 Illustration from the book *The Evolving House: Rational Design* by Alfred Farwell Bemis, 1938.

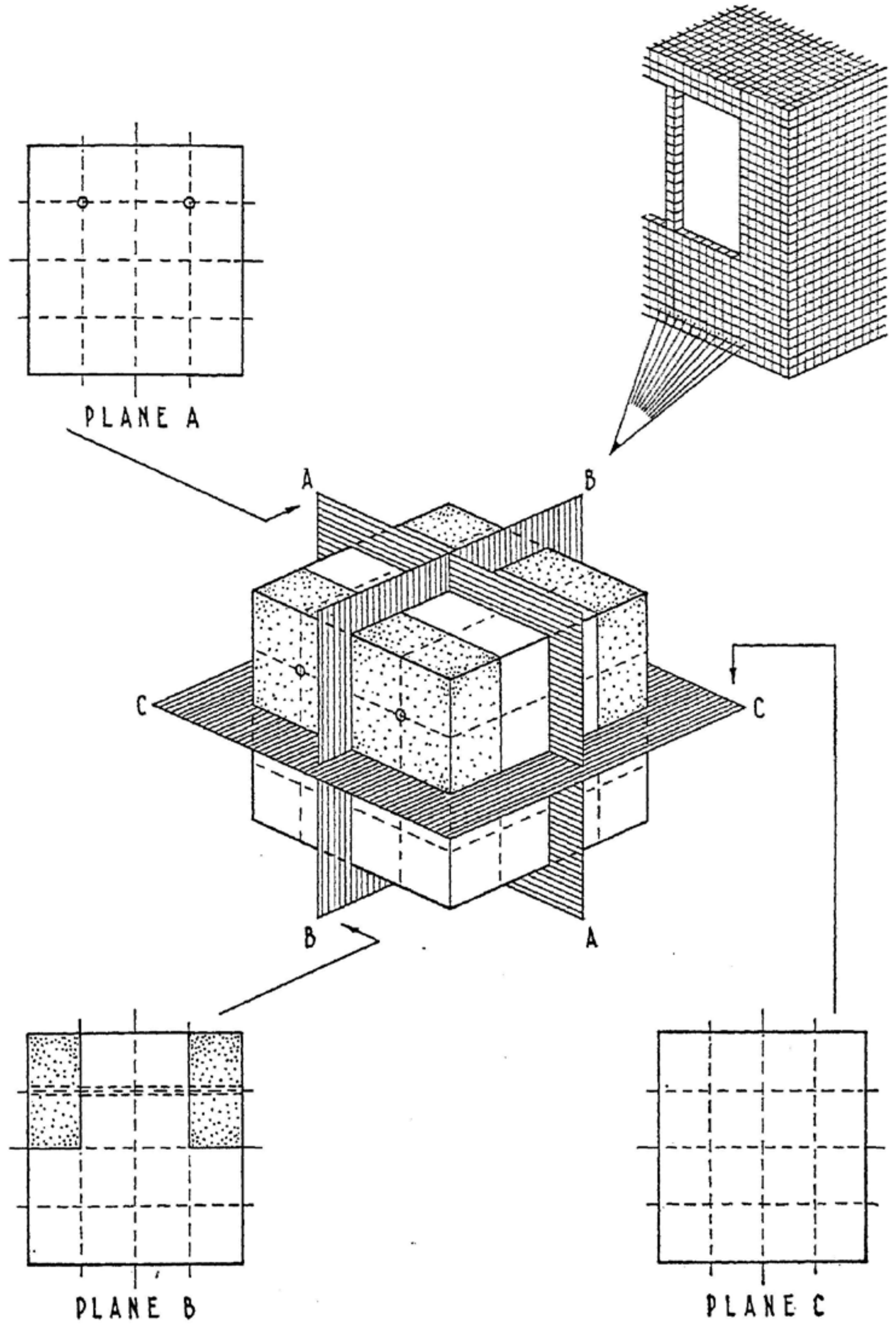


Fig. 29. AXIAL PLANES—DIFFERENTIATION OF FUNCTION

A marginal cube of a structural member is shown subdivided into its 64 tertiary cubes. The specific function of interconnection is assigned to the small shaded cubes. The member thus designed is symmetrical about modular axial planes A and B, but asymmetrical about C

29

Methodology

1. Discrete computational design and fabrication methods

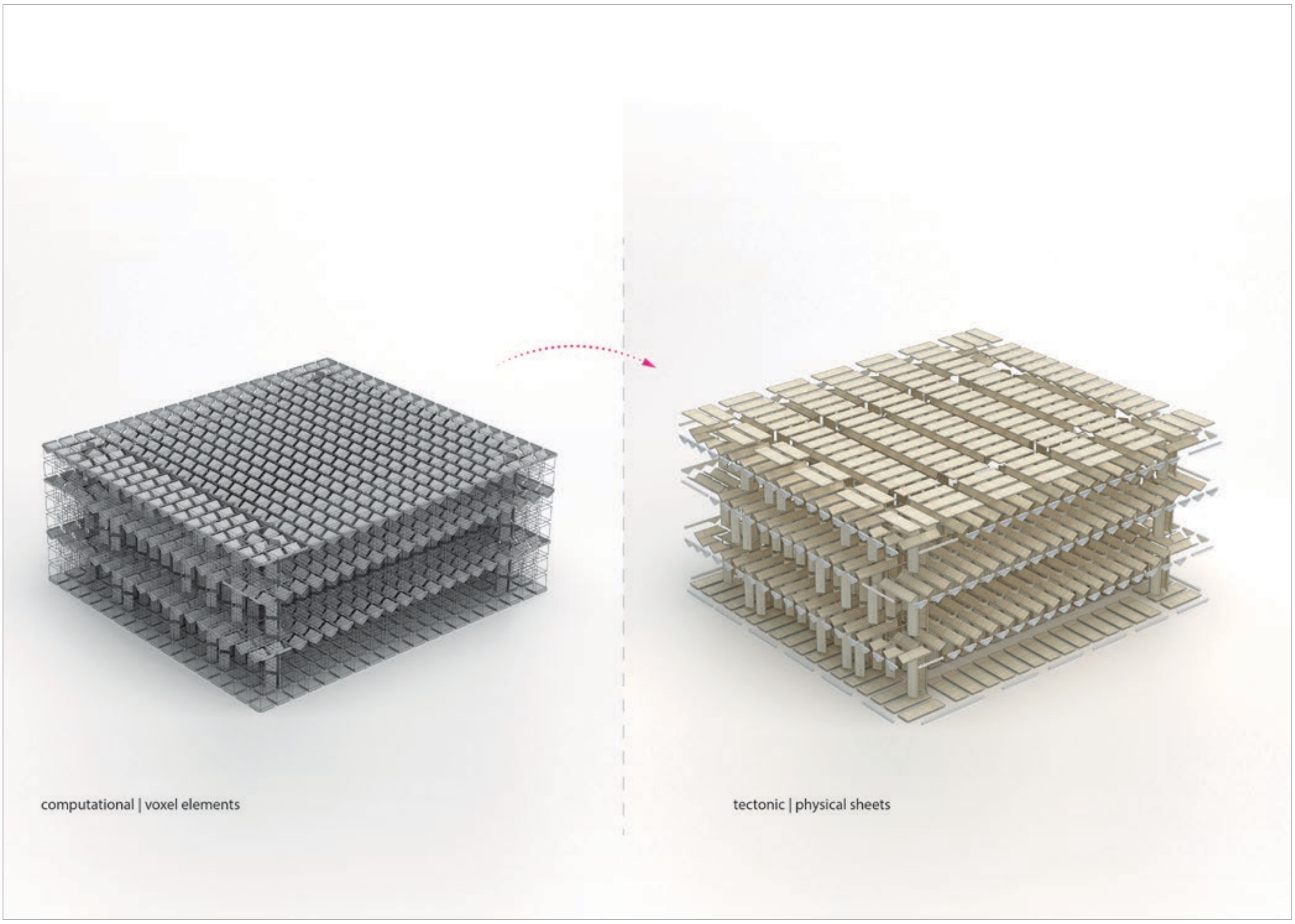
Computation was used to digitally assemble individual parts and evaluate or analyse the resulting compositions. The assembly process is based on aggregation, where the rules of connection are defined as a kind of grammar. Combinatorics is another useful process, where different combinations of elements are coded. Voxels are organised in a 3D grid and are filled with data: geometric elements, vectors or mere numbers. Subsequently, interactions between the voxels are coded and evaluated. Polyhedral geometries are often used as they are discrete volumes that can 'tile' a volumetric space and offer more complex versions of a grid-like voxel space.

Robots are digitally simulated to assemble discrete parts. The discrete unit in the fabrication process corresponds with the discrete unit in the computation process, allowing both to run in parallel. In this case, a robot can build and edit structures from small parts, making decisions along the way. The combination of discrete design and discrete fabrication can be understood as the aforementioned 'digital materials'. The different projects discussed here develop a short, integrated and continuous production chain based on generic, serialised and versatile building blocks cut from 2D timber sheet materials.

The competition for the Nuremberg Concert Hall (2018) is a key example of this approach **(30)**. The entire building consists of repeating timber modules. In a digital workflow, these Lego-like elements can be prefabricated using automated technologies such as large CNC-machines and industrial robots, and can then be assembled onsite. The building is based on a repeating V-shaped timber section of 3 × 1.2 m. This section repeats horizontally to construct slabs, and vertically to create walls and columns **(33)**. This efficient workflow reduces the build time on site and ultimately delivers a proposal lower than the envisaged cost. An algorithmic procedure was developed to organise the hundreds of generic timber modules into a functional building **(31)**.

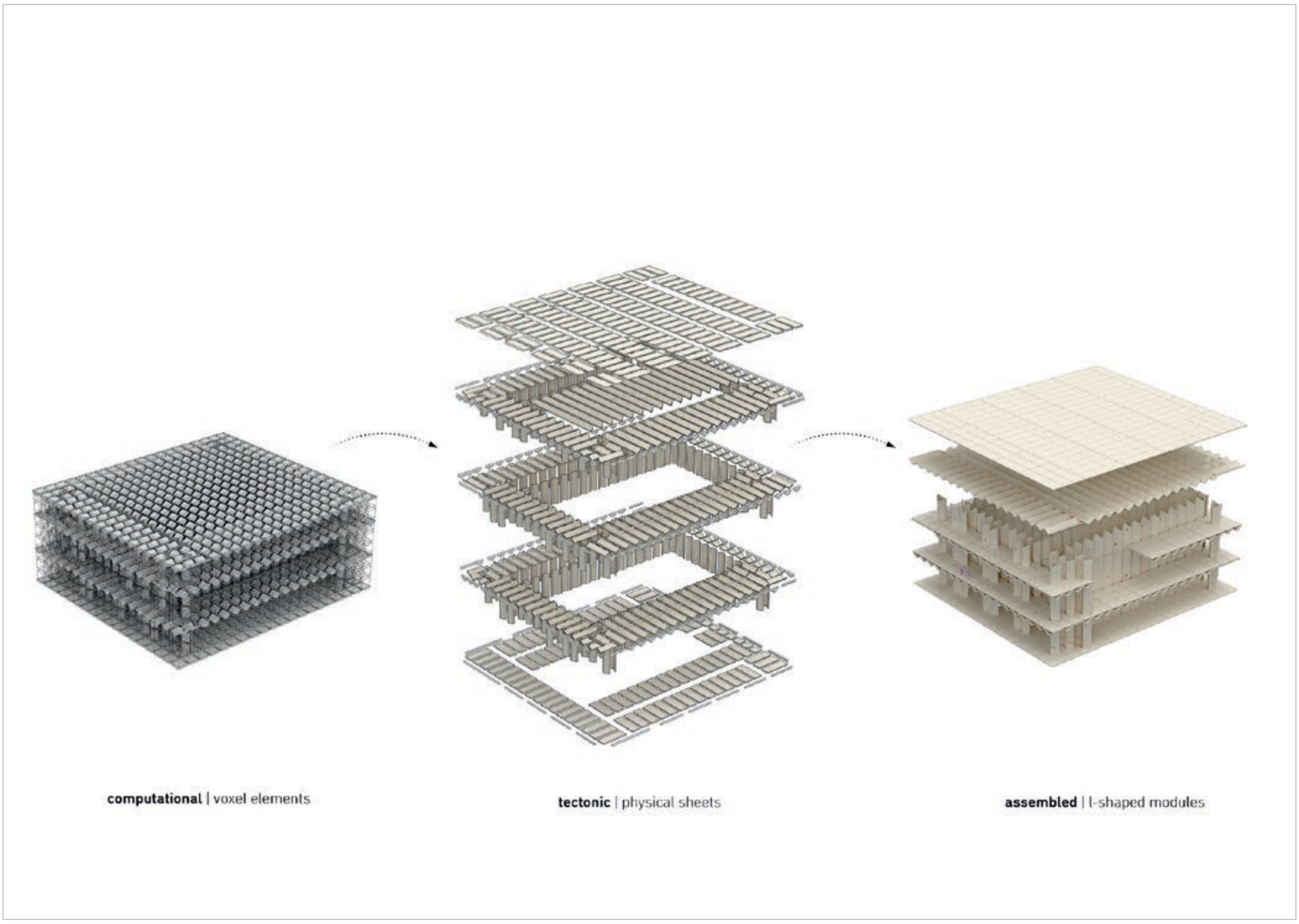
30

30 Proposal for the Nuremberg Concert Hall. Architecturally, this method results in a monolithic space defined by a single repeating element.



31

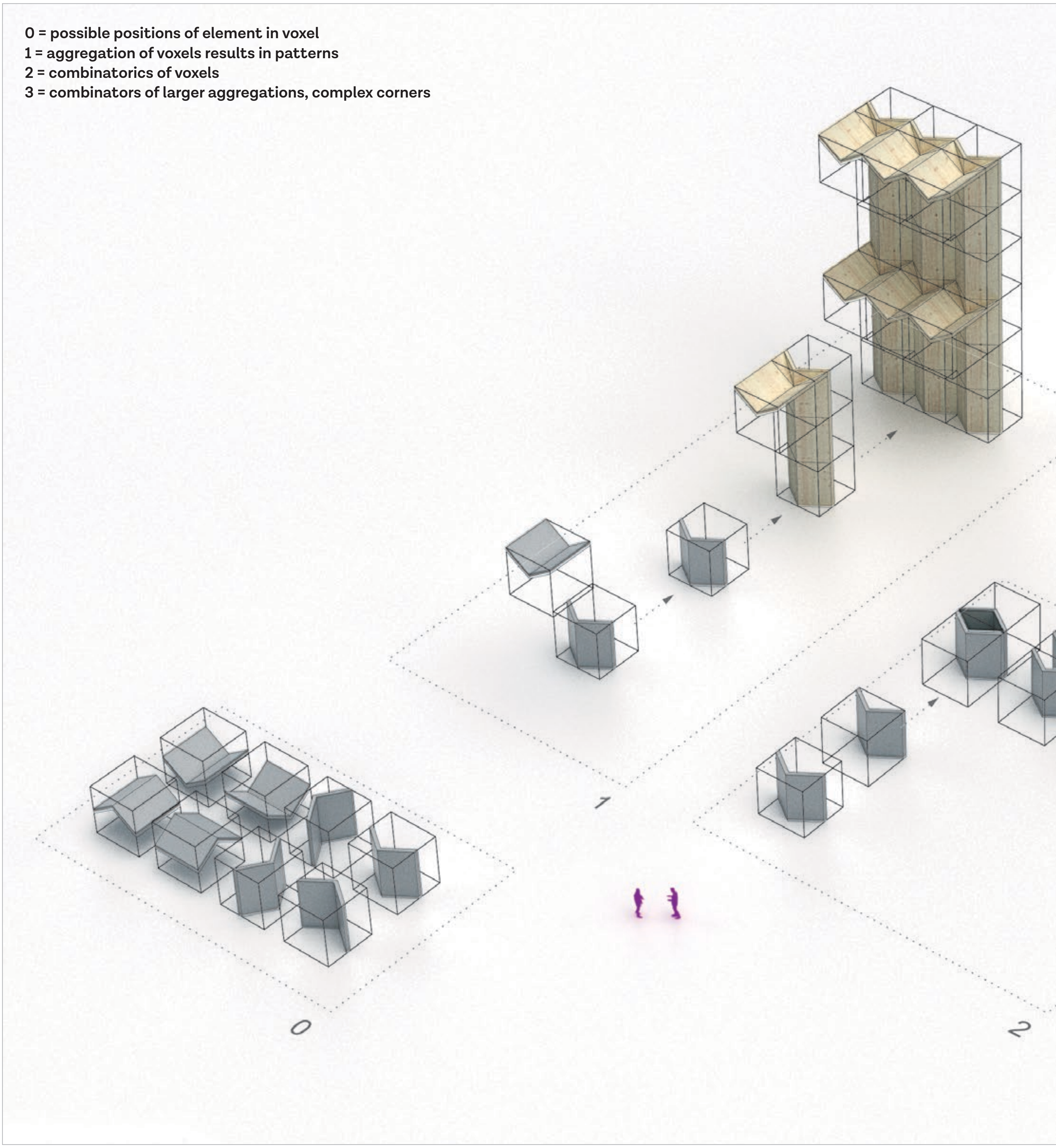
31 An algorithm was developed for The Nuremberg Concert Hall proposal, which assembles voxels into functional patterns of timber building blocks.

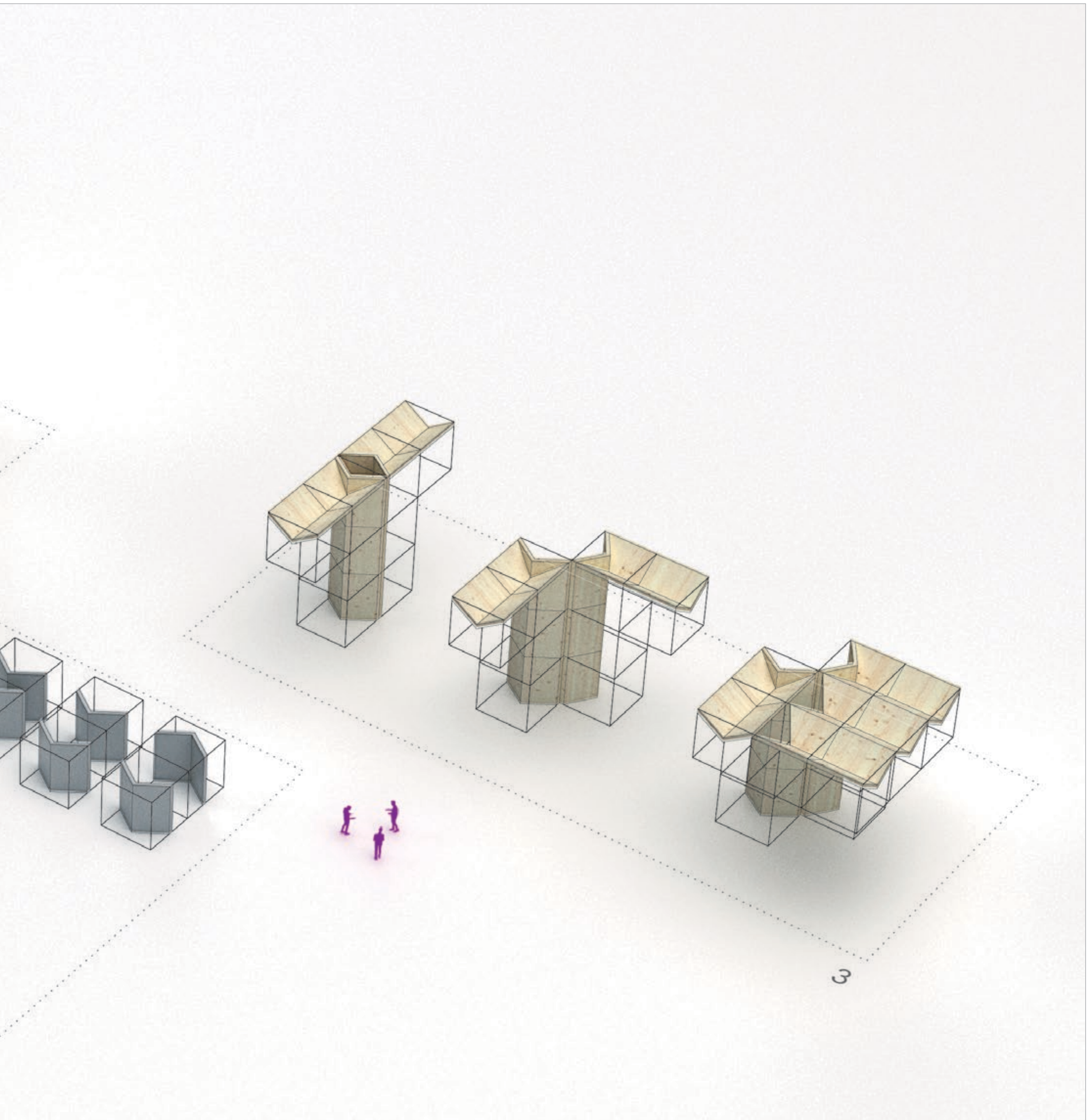


32

32 The Nuremberg Concert Hall combines discrete design and fabrication.
It demonstrates how modularity can be reinterpreted in a digital way, where building elements are akin to pixels.

33 (overleaf) The voxel contains an abstract V-shaped building block which can be recombined to construct different architectural instances.


0 = possible positions of element in voxel
1 = aggregation of voxels results in patterns
2 = combinatorics of voxels
3 = combinators of larger aggregations, complex corners
0
1
2



33

2. Large-scale prototyping and iterative testing, in collaboration with structural engineers

A series of 1:1 prototypes were constructed to evaluate and test the premise of a discrete architecture **(34)**. The Tallinn Architecture Biennale installation was conceived as an abstract fragment of a larger housing block. The design of the building blocks was based on off-standard sheets of 18 mm exterior plywood (3.3 × 1.35 m). Using a CNC machine, each sheet was cut into a series of parts and assembled into a stiff building block capable of bearing structural loads. These building blocks were prefabricated and individually assembled onsite **(37)**. The geometry and dimensions of the part are derived from the sheet, while the grid is defined by the overarching housing block. The discrete part was designed as a box beam-like element, an external structural skin with internal frames. These frames are notched in the skin and set out modular connectivity for post-tension rods that run laterally across elements. Unlike traditional post-tensioned structures, these threaded rods only act locally and are therefore discrete. Architecturally, the elements read longitudinally, while the internal stiffening frames and post-tension rods form a continuous lateral structure. This results in a timber monolith composed of parts, which can subsequently be altered, reversed and re-assembled.

The work was further iterated for installations at the Royal Academy of Arts in London **(38–40, 43)**, Shenzhen Biennale and a workshop at Hasselt University.


34

34 1:1 experimentation is a fundamental driver for the project, in this case large-scale elements were tested for a workshop at Tongji University, Shanghai.

35

37

36

35–6 Prefabricated elements for the Tallinn Architecture Biennale being transported to site.

37 The elements are assembled onsite. Threaded rods are used to tension the blocks together.

38–9 (overleaf) Real Virtuality at the Royal Academy of Arts in London, 2019.

38

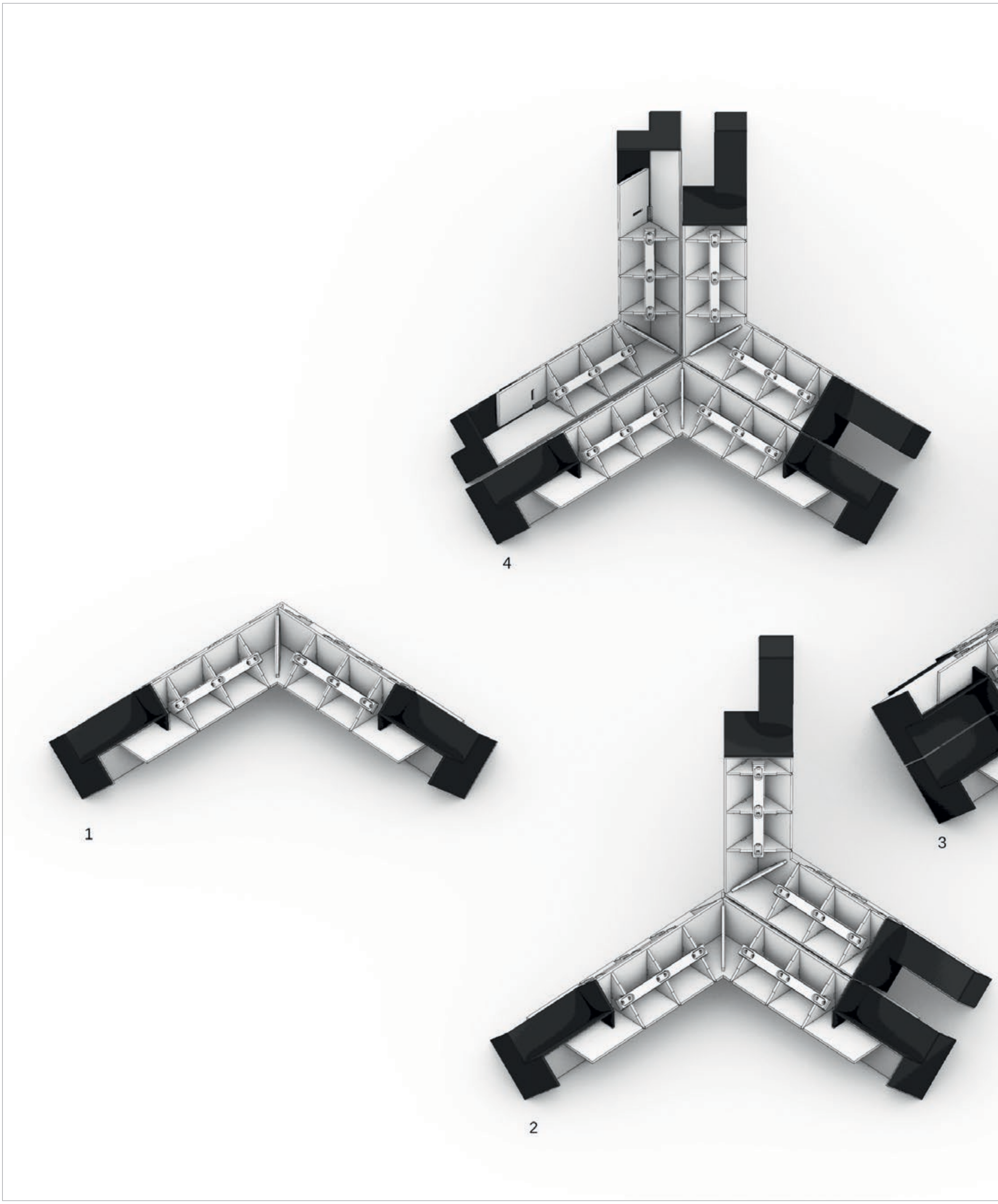
39

3. Experimental proposals for full-scale buildings

As a means to provide context for the 1:1 installations, the work has been tested in proposals for full-scale buildings in collaboration with multi-disciplinary consultants in order to address concerns on topics such as climate, programme and circulation **(40, 43)**. The installation at the Royal Academy of Arts in London is linked to a proposal for a multi-family house in Wemmel, Belgium (2015); while the installation at the Tallinn Architecture Biennale is connected to research into housing, resulting in a design for a 200-m-long housing block (2018) **(12, 22)**. The proposal for a concert hall in Nuremberg scales up material from plywood to cross-laminated timber (CLT). This scaling up and iteration between competition proposals and 1:1 installations is important and mutually influential.

The process of scaling-up and applying the research to larger proposals involved addressing technical questions such as thermal properties, building cost and lifecycle analysis. For example, the proposal for the concert hall in Nuremberg included research on fire regulations in collaboration with a fire consultant. Ultimately, it was the performance of the building with respect to fire that defined the thickness of the CLT sheets rather than purely its structure. This resulted in a uniform thickness of CLT sheets throughout the entire building, which conceptually and practically reinforced the discrete approach.

40 Real Virtuality can be understood as a fragment of a larger building.


4
1
3
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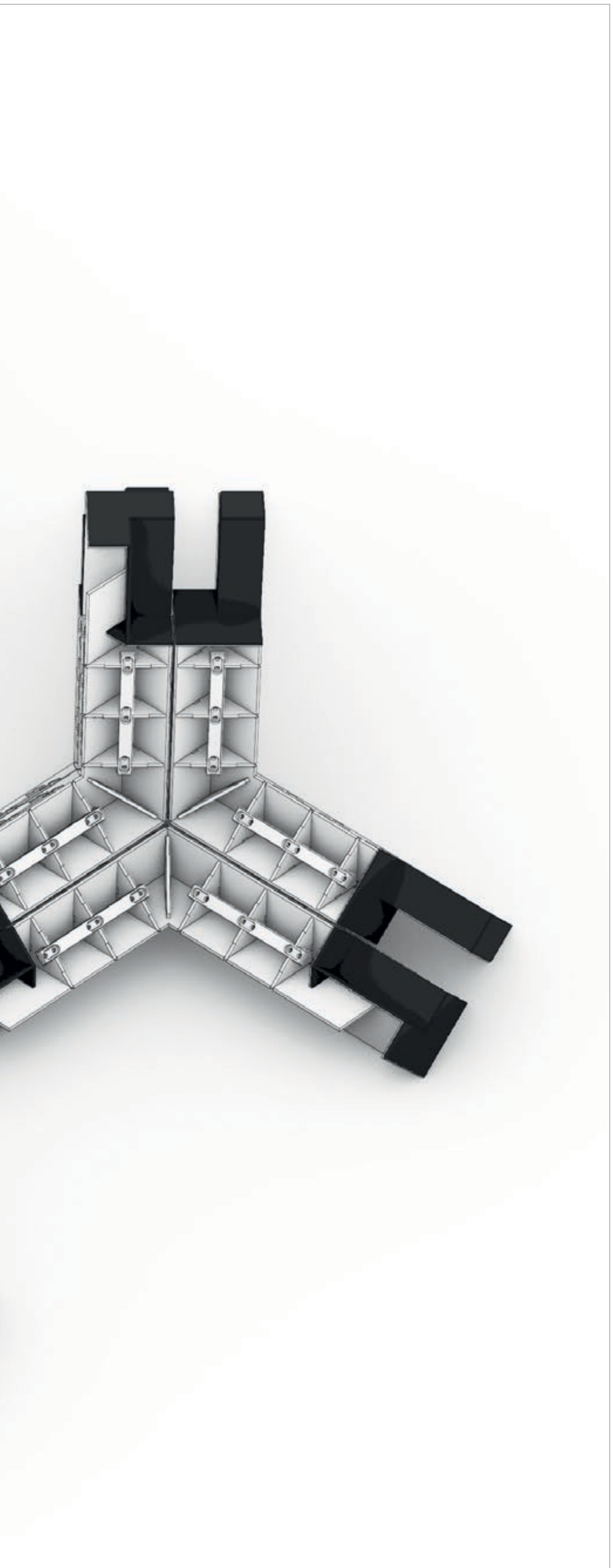

41

41 Building blocks diagram for Real Virtuality at the Royal Academy.

4. Theoretical and historical framing through writing and the peer-to-peer community

The work cannot be seen separately from its architectural argument and debate around the digital. Theoretically the work engages with 'mereology', or part-to-whole relations (Köhler 2016). It also builds on architecture theories and histories of computational design and digital theory such as the work of Mario Carpo, Jose Sanchez, Philippe Morel and Roberto Bottazzi. Historically, it situates itself in relation to automation, as a parallel to industrialisation in modernism. Significant practitioners working in this field include Roland Snooks, Jose Sanchez (University of Southern California), Casey Rehm (SCI-Arc), Daniel Köhler and Rasa Navasaityte (The University of Texas at Austin), and Philippe Morel (ENSA Paris-Malaquais). At UCL, this group includes Mollie Claypool, Igor Pantic, Tyson Hosmer and Manuel Jimenez Garcia. The work has also influenced the agendas of studios and research labs at the Estonian Academy of Arts, University of Southern Denmark, University of Bologna, TU Darmstadt, The University of Texas at Austin and Texas A&M University.

42 Designed as a primitive shed, The National Museum of Finland is another experiment with large-scale timber modules, assembled to form an A-frame.

42

Dissemination

The 2017 Tallinn Architecture Biennale that included Retsin's building was visited by 200,000 visitors. The work has been further discussed in nine published articles by the author and has featured in 13 peer-reviewed papers and 20 online articles. It has been discussed in seven academic papers for conferences, including ACADIA 2019 in Austin, and has led to two keynotes and 32 public lectures, including a symposium organised by the Swiss Architects' Association in Zurich on digital fabrication. It has been exhibited internationally, including at five biennales.

Publications

- Retsin has written on the subject for *AA Files* (2019) and has co-authored a related book for *Detail* (2019);
- Published in print, including on the cover of *C3* and *The Architect's Newspaper* (2019);
- Gilles Retsin guest-edited an issue of *Architectural Design* on the discrete (2019);
- Discussed in articles by Mario Carpo in *Artforum* (2020), *Architectural Design* (2019) and *Architectural Record* (2019);
- Discussed in the book *Architecture for the Commons: Participatory Systems in the Age of Platforms* by Jose Sanchez (2020);
- Featured extensively online, including *ArchDaily* (2019), *e-flux* (2019) and *Domus* (2017).

Films

- *Sustainable Cities Can't Rely on Concrete. Let's Try Algorithmically Designed Timber Buildings* (2019). Produced by Mashable. [Viewed 9 December 2020]. https://mashable.com/video/building-with-timber-instead-of-concrete/?europe=true by Maria Dermentzi
- *A Quoi Ressemble la Maison du Futur?* (2019). Produced by Le Nouvel Observateur. [Viewed 9 December 2020]. www.nouvelobs.com/2049/20191011.OBS19666/smart-ecolo-partagee-a-quoi-ressemble-la-maison-du-futur.html

Solo Exhibitions

- *Digital Turn, Design Computation Lab*, Building Centre, London (2018)
- *in part whole*, MBUS Design Gallery, Miami (2017)

Group Exhibitions

- Bi-City Biennale of Urbanism/Architecture, Shenzhen (2019)
- *DigitalFUTURES*, Tongji University, Shanghai (2019)
- *Discrete Familiars*, Fort Worth Community Arts Center (2019)
- *Environment[al]*, SCI-Arc, Los Angeles (2019)
- Experimental Architecture Biennial, Prague (2019)
- *Feedback*, International Biennial of Architecture, Buenos Aires (2019)
- *Invisible Landscapes*, Royal Academy of Arts, London (2019)
- KANAL Centre Pompidou, Brussels (2018)
- *Meta Utopia*, Zaha Hadid Gallery, London (2017)
- *Printing the World*, Centre Pompidou, Paris (2017)
- Tallinn Architecture Biennale (2017)

Lectures

- Aarhus University (2020)
- Hasselt University (2020)
- Hong Kong University (2020)
- Kent State University, Ohio (2020)
- Rensselaer Polytechnic Institute, New York (2020)
- Universidad Europea de Madrid (2020)
- Estonian Academy of Arts, Tallinn (2019)
- Experimental Architecture Biennial, Prague (2019)
- RMIT University, Melbourne (2019)
- Royal Academy of Arts, London (2019)
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- University of Sydney (2018)
- Victoria University, Wellington (2018)
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- Tallinn Architecture Biennale (2017)

Keynotes

- Federation of Swiss Architects, Zurich (2019)
- Nouvel Obs, Paris (2019)

Project Highlights

The work led to a first prize at the Tallinn Architecture Biennale, a direct commission for an installation at the Royal Academy of Arts in London, and a solo show at MBUS Design Gallery in Miami. Further to this, it resulted in an invitation to co-edit two books related to the topic: *Discrete: Reappraising the Digital in Architecture* for *Architectural Design* (2019) and *Robotic Building: Architecture in the Age of Automation* for *Detail* (2019). On the basis of this work, Retsin has held visiting professorships at RMIT University and The University of Hong Kong.

The work has significantly influenced what Mario Carpo (The Bartlett, UCL) describes as a historic 'second digital turn' in architecture and has been extensively discussed by architectural historians Antoine Picon (Harvard Graduate School of Design) and Theodora Vardouli (McGill University).

43

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